UDC 551.510.3:551.501.7:551.507.362.1

Short Time Period Atmospheric Density Variations and Determination of Density Errors From Selected Rocketsonde Sensors

BRUCE T. MIERS, ELTON P. AVARA, and **ROBERT O. OLSEN**—*Atmospheric Sciences Laboratory, U.S. Army Electronics Command, White Sands Missile Range, N. Mex.*

ABSTRACT—Atmospheric density variations as observed from three series of concentrated meteorological rocket soundings are described. Arcasonde, Datasonde, and inflatable falling sphere sensors were used to determine the density structure. Data reduction methods are discussed for bead thermistor instruments (Arcasonde and Datasonde) and inflatable falling spheres. Error sources of both systems are discussed. The best estimate of the standard deviation of the density noise for the Arcasonde and Datasonde instruments was found to be approximately 1.08 percent.

1. INTRODUCTION

A knowledge of the vertical and horizontal variation of atmospheric density is required to solve problems such as reentry effects on missiles and their components. For guided reentering vehicles, it has been shown that maximum reentry heating commonly occurs in the 50-to 70-km altitude region of the atmosphere. The deceleration (in g's) of a reentry vehicle is given by the dynamic pressure, $q=0.5\rho V^2$, divided by the ballistic coefficient, $B=W/C_DA$, where ρ is the atmospheric density, W the weight of the vehicle, V the relative velocity, C_D the drag coefficient, and A the reference area of the vehicle.

Currently at White Sands Missile Range (WSMR), three types of sensors are used to gather atmospheric density data in the 50-to 70-km altitude region. These sensors are the Arcasonde 1A, Datasonde, and the inflatable falling sphere.[1] To provide the best atmospheric density data, we must determine sensor error bounds and observe atmospheric variations. Improved instrumentation and refined correction techniques have led to greater confidence in the reported density variations. Ballard (1967) summarized the research concerning the measurement of temperature in the stratosphere and mesosphere. Improved mounting configurations permit rapid heat dissipation, and the aerodynamic heating and radiation corrections reduce the observed values to ambient values. Muench (1971) has suggested that about half the difference between radiosonde and rocketsonde temperatures is due to infrared cooling of the radiosonde thermistor and that the remaining difference is due to the radiosonde thermistor riding up through the wake of a balloon cooled by radiative and adiabatic processes. Corrections for these effects are about +7. 5°C for a night flight and +4.4°C for a day flight in the 30-to 40-km altitude region of the atmosphere. The accuracy of density data from inflatable spheres has been found to vary according to altitude and radar type (Engler 1965). With an FPS–16 radar, the root-mean-square (rms) error in density varies from 3.5 percent at 65 km to 3 percent at 50 km and below.

This paper will discuss the methods of data reduction, possible errors in the reduction methods and radiosonde tie-on values, results of three concentrated series of meteorological rocket soundings, noise variance of the density data, and a recommendation for improving the accuracy of the data.

2. METHODS OF DATA REDUCTION

With rocketsonde temperature versus height measurements and a pressure obtained from a radiosonde, density and pressure may be calculated for the upper stratosphere and lower mesosphere. The general procedure used to calculate these parameters is to combine the hydrostatic equation

$$dp=-\rho g dz \tag{1}$$

and the equation of state

$$p=\left(\frac{R}{M}\right)\rho T \tag{2}$$

to yield

$$\frac{dp}{p}=-\left(\frac{Mg}{RT}\right)dz \tag{3}$$

where p is pressure, ρ is density, z is height, g is the acceleration due to gravity, T is ambient temperature, R is the universal gas constant, and M is the molecular weight of air. After assuming that the temperatures are constant over thin layers, integration of eq (3) over the layers between successive heights gives

$$p_{i+1}=p_i \exp\left[-g\,(z_{i+1}-z_i)/R'\overline{T}_i\right] \tag{4}$$

[1] Mention of a commercial product does not constitute endorsement.

for $i=0, 1, \ldots, n-1$ where $R'=R/M$ is the gas constant for dry air, g is the acceleration of gravity and is assumed constant, $\overline{T}_i$ is the mean temperature through the layer z_i to z_{i+1}, and z_n is the maximum height of the rocketsonde sounding. The values of pressure, p_0, and height, z_0, are taken from radiosonde data; z_i and T_i $(i>0)$ are rocketsonde heights and temperatures. Once the pressures are calculated, densities are obtained from the equation of state.

In the case of the inflatable falling sphere, a measurable drag force is exerted on the sphere, and the atmospheric density is proportional to this force. The computation of density requires measurements of velocity, acceleration, and drag coefficients. When these are known, density can be computed by

$$\rho=\frac{M(g_z-\ddot{z}-C_z)}{\frac{1}{2}C_D A|V|(\dot{z}-W_z)+V_B g_z} \tag{5}$$

where ρ is the atmospheric density, M is the mass of the sphere, g_z is the acceleration of gravity (Coriolis forces neglected), $\ddot{z}$ is the vertical acceleration of the sphere, C_z is the Coriolis acceleration in the vertical, C_D is the drag coefficient of the sphere, A is the cross-sectional area of the sphere, V is the relative volocity of the sphere, $\dot{z}$ is the vertical velocity of the sphere, W_z is the vertical wind velocity, and V_B is the volume of the sphere. It is most important that the drag coefficient of the sphere be properly evaluated for each density calculation. From fluid dynamics considerations (Vennard 1940), it can be shown that the drag coefficient of a sphere is a function of Reynolds number and Mach number. Tables of drag coefficients have been developed from wind tunnel and ballistic range tests, and these are used in the calculation of density. The flow conditions experienced by an inflatable sphere released above 100 km range through supersonic, slip-flow, transonic, continuum, and subsonic.

3. POSSIBLE ERRORS IN REDUCTION METHODS

Errors in density values can be attributed to uncertainties in rocketsonde temperatures (Ballard and Rubio 1968), radiosonde temperatures (Camp and Caplan 1969, Muench 1971), and discrepancies in the radiosonde computed heights. According to Kays and Avara (1970), errors in the computed pressures and densities can be determined in a general manner by using eq (4). Taking the natural log of each side of eq (4) we arrive at

$$\ln p_{i+1}=\ln p_i-[g_i(z_{i+1}-z_i)/R'\overline{T}_i]. \tag{6}$$

Now let Δp_i, Δz_i, and ΔT_i be the errors associated with p_i, z_i, and $\overline{T}_i$. By assuming that g and R' are constant, we find, by differentiation of eq (6), that

$$\frac{\Delta p_{i+1}}{p_{i+1}}=\frac{\Delta p_i}{p_i}-g\,\frac{(z_{i+1}-z_i)}{R'\overline{T}_i}\left(\frac{\Delta z_{i+1}-\Delta z_i}{z_{i+1}-z_i}-\frac{\Delta\overline{T}_i}{\overline{T}_i}\right). \tag{7}$$

Now in the same manner, eq (2) yields

$$\frac{\Delta p_i}{p_i}=\frac{\Delta\rho_i}{\rho_i}+\frac{\Delta T_i}{T_i}. \tag{8}$$

Specific values, as used by Kays and Avara (1970), can be substituted into these equations and the magnitude of the error determined. $\Delta p_i/p_i$ can be considered the relative error in p_i and 100 $\Delta p_i/p_i$ is the percentage error. Taking z_0 as 26.86 km, z_1 as 27.49 km, T_0 as 233.8°K, T_1 as 235.0°K, ΔT_0 as -2.0°C, $\Delta\overline{T}_0$ as -1.0°C, and assuming Δp_0, Δz_0, and Δz_1 all zero, we find that

$$\frac{\Delta p_i}{p_i}=\frac{(9.73)(27.49-26.86)}{(0.287)(234.4)}\left(\frac{-1.0}{234.4}\right)=-0.000388.$$

If $\Delta z_i=\Delta\overline{T}_i=0$ for $i\geq 1$, then

$$\frac{\Delta p_i}{p_i}=\frac{\Delta p_1}{p_1}=-0.000388.$$

Now let $\Delta T_0=-2.0$°C and $\Delta p_0=0$ and compute the change in density

$$\frac{\Delta\rho_0}{\rho_0}=\frac{\Delta T_0}{T_0}=-\frac{(-2)}{233.8}=0.00856.$$

When $\Delta T_i=0$, we find that

$$\frac{\Delta\rho_i}{\rho_i}=\frac{\Delta p_i}{p_i}=-0.000388 \text{ for } i=1, 2, \ldots, n.$$

An error in the height of the radiosonde tie-on level will also cause an error in density. The expected error in pressure at 20 mb (the usual tie-on level) using a hypsometer-type instrument is 0.25 mb (Inter-Range Instrumentation Group 1965), and this corresponds to a height difference of about 78 m. Comparisons of radiosonde-determined heights with radar-determined heights of the same instrument at WSMR have shown that differences of as much as 604 m are possible between these two systems. In these tests, FPS–16 radars tracked the radiosonde (equipped with hypsometer), and then the altitude-versus-time determinations were compared. In some tests, two FPS–16 radars tracked the same radiosonde; in these cases, agreement between radars was good (within 5 m), while the radiosonde determined altitudes showed a greater difference. Using 300 m as a height error and letting $\Delta p_0 = \Delta\overline{T}_0 = 0$, the value of $\Delta p_i/p_i$ becomes -0.0433. Further, if $\Delta z_i = \Delta\overline{T}_i = 0$, then $\Delta p_i/p_i = \Delta p_1/p_1 = -0.0433$ for $i \geq 1$. The change in density can be obtained by letting $\Delta p_0 = \Delta T_0 = 0$ and then $\Delta\rho_0/\rho_0 = 0$ when $\Delta T_i = 0$; $\Delta\rho_i/\rho_i = \Delta p_i/p_i = -0.0433$ when $i \geq 1$. This is a change in density of more than 4 percent. Therefore, an error in height of 300 m would be by far the greatest contributor to an error in density.

Errors in density data from inflatable falling spheres have been discussed by Engler (1965), Pearson (1966), and Faucher et al. (1967); therefore, no details will be given in this paper. Generally, the main error in sphere density measurements is due to inaccuracy in measuring the accelerations and uncertainty in the drag coefficients, particularly in the transonic flight regions. The sphere is usually tracked with an FPS–16 radar that was designed to track high velocity, low acceleration missiles, but the sphere usually falls at a low velocity and a high acceleration. Luers and Engler (1969) estimate that normal tracking error (one standard deviation) to be about 2 percent. From the drag equation, it can be shown that the density error is proportional to the acceleration error and in turn the acceleration values depend upon how well the radar tracks the sphere. Acceleration values of less than 1 $m \cdot s^{-2}$ computed from radar data are subject to a large uncertainty. These values usually occur below 55 km. Another source of error in the sphere-derived densities is the assumption of no vertical wind in solving eq (5). Also, in the reduction method a temperature is selected (for determining Mach number) from the 1962 US Standard Atmosphere (COESA 1962) as an initial value so that calculations can begin. This temperature value introduces errors in the first few data points, but its effect becomes less than 1 percent after the first 4 km of usable data.

4. RESULTS FROM A CONCENTRATED SERIES OF SOUNDINGS

Three concentrated series of meteorological rocket firings were conducted at WSMR to evaluate the noise variance of the density data and to observe the atomspheric variability. Times and types of soundings that produced usable data are listed in table 1. A complete tabulation of data taken at these times is published by the National Oceanic and Atmospheric Administration (1969, 1970). Standard data reduction procedures and correction techniques were used to arrive at the final values of density (Novotny and Grazier 1970).

A comparison of the mean density profiles obtained by bead thermistor and mean sphere soundings with the Standard Atmosphere (COESA 1962) is given in figure 1. Below 40 km, the bead thermistor density values are generally less than the 1962 Standard Atmosphere values while above 40 km the bead values are greater than the standard. The percentage difference between the three bead thermistor curves can be explained easily in terms of seasonal changes such as those described by Morris and Miers (1969). For the sphere data, variations from the standard are less than 10 percent except in the 70- to 80-km and 90- to 100-km regions. The large variations between 90 and 100 km are usually attributed to the radar tracking problem and the temperature selection feature of the reduction program mentioned in the above section. The departure in the 70- to 80-km region is probably due to the uncertainty in the drag coefficients referred to in the same section. Sphere density values below 70 km are within 5 percent of the 1962 Standard Atmosphere and are in general agreement with densities derived from the bead sensors. In the regions of common data points (February spheres and beads), the largest difference is 3 percent at 58 km, all other points being within 2 percent. We see in table 2 that the 2000 MST sounding on May 10 shows greater departure from the Standard Atmosphere

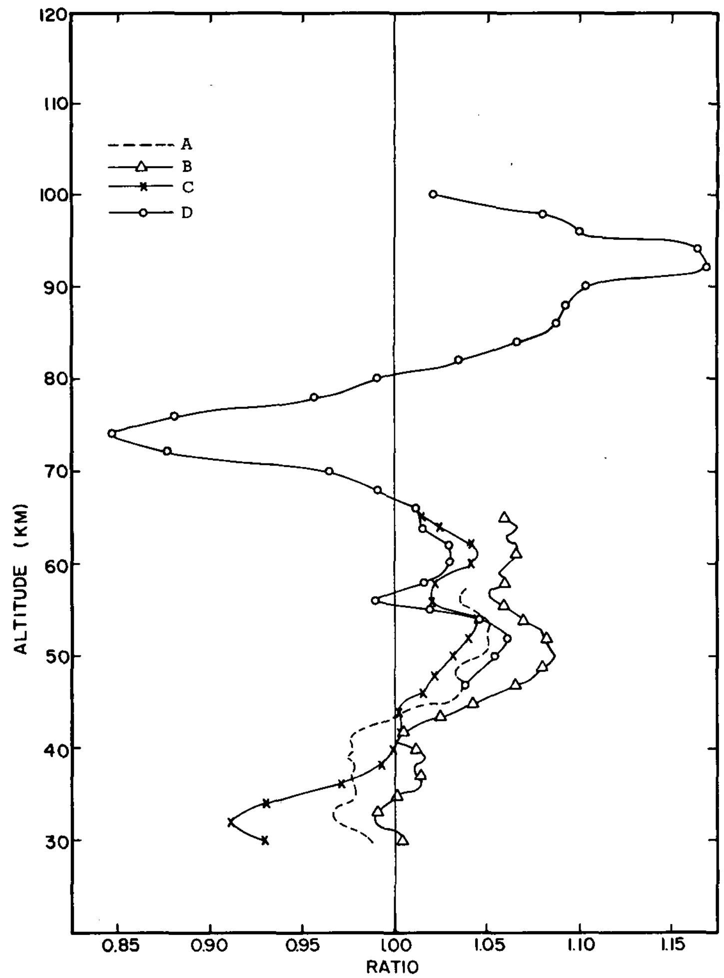

FIGURE 1.—Ratio of the (A) April 1969 (bead), (B) May 1969 (bead), (C) February 1970 (bead), and (D) February 1970 (sphere) mean profiles to the 1962 Standard Atmosphere ($\rho/\rho_{std.}$).

than the 1100 MST sounding on May 9. However, these soundings do not show the consistency from level to level that one would expect to see in the atmosphere during this particular season. When comparing these soundings to the nearby bead thermistor soundings, we found percentage differences ranging from 0.19 percent to 13.14 percent. Wright (1969) has pointed out this type of disagreement in other sphere and bead soundings.

On three occasions (table 1), soundings were made with a time separation of only 3 min and a horizontal distance separation of less than 10 km. Figure 2 shows these soundings in relation to the 1962 Standard Atmosphere. The percentage difference between the soundings is usually less than 1 percent with the April soundings averaging 0.81 percent, the 2130–2133 soundings on May 10 averaging 0.40 percent, and the 2330–2333 soundings on May 10 averaging 0.65 percent. If one assumed that the atmosphere changes very little in the stratosphere for the stated time and space intervals, the sensors indicate good repeatability. Areas of the atmosphere where significant changes in density have occurred in a short period of time and space have been observed by Beyers and Miers (1970). Their observations were from instrumentation similar to the rocketsonde sensors used

Table 1.—*Times and types of soundings that produced usable data during the short-term sampling intervals in 1969 and 1970*

Date	Time	Sensor
1969	(MST)	
Apr. 26	2040	Arcasonde
Apr. 26	2100	Arcasonde
Apr. 26	2200	Arcasonde
Apr. 26	2250	Arcasonde
Apr. 26	2253	Arcasonde
Apr. 26	2330	Arcasonde
May 9	1100	Sphere
May 9	1130	Arcasonde
May 10	2000	Sphere
May 10	2030	Arcasonde
May 10	2100	Arcasonde
May 10	2130	Arcasonde
May 10	2133	Arcasonde
May 10	2200	Arcasonde
May 10	2230	Arcasonde
May 10	2300	Arcasonde
May 10	2330	Arcasonde
May 10	2333	Arcasonde
1970		
Feb. 9	1000	Sphere
Feb. 9	1006	Datasonde
Feb. 9	1100	Arcasonde
Feb. 9	1203	Datasonde
Feb. 9	1230	Sphere
Feb. 9	1235	Datasonde
Feb. 9	1300	Sphere
Feb. 9	1330	Datasonde
Feb. 9	1334	Sphere

in this study but were attached to a large zero-pressure balloon floating near 48-km altitude. These observations showed a density change greater than 10 percent over a horizontal distance of about 4 km and a time span of 30 min. There are no such variations observed in the data presented in this paper.

Figure 3 is a plot of the ratio values of sphere and bead sensors flown within 5 min of one another. Because the time and space separations of these soundings are small (4–5 min and 5–10 km), one would expect good agreement among the soundings. However, differences of as much as 11 percent are noted. The profiles from the bead sensors indicate a general similarity, and are smoother than the sphere profiles. The sphere profiles indicate larger density variations from level to level and less similarity with the passage of time. In the areas of common data points, there is general agreement between the mean density data derived from the bead thermistor and sphere systems (see table 2) but the individual sphere soundings show more variation. From these data, one has more confidence in the bead data than in the sphere data because of the consistency of the bead values. Miller and Schmidlin (1971) have also shown the repeatability of the Datasonde instruments.

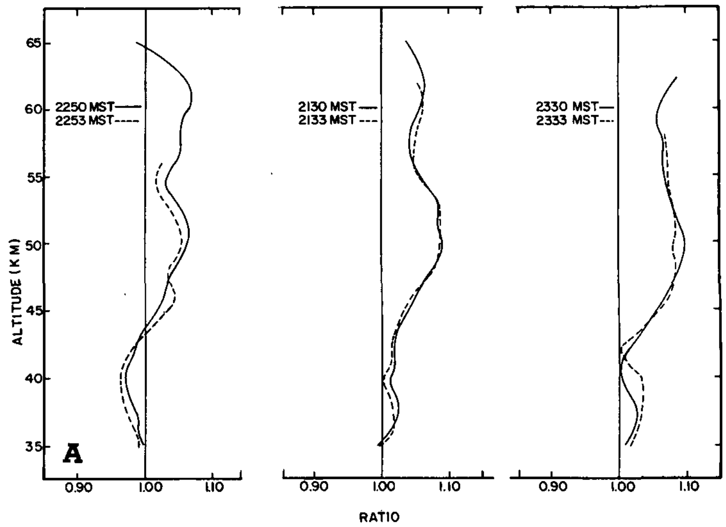

Figure 2.—Ratio of paired bead thermistor soundings with 3-min time separation to the 1962 Standard Atmosphere ($\rho/\rho_{std.}$) for (A) Apr. 26, 1969; (B) and (C) May 10, 1969.

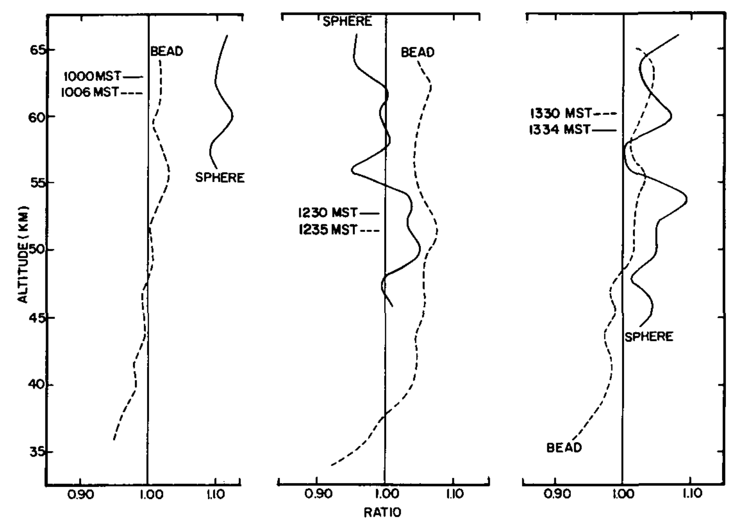

Figure 3.—Ratio of paired bead thermistor-inflatable sphere soundings to the 1962 Standard Atmosphere ($\rho/\rho_{std.}$), with approximately 5-min time separation on Feb. 9, 1970.

5. NOISE VARIANCE OF THE DENSITY DATA

A paired-data test was used to determine the first estimate of the standard deviation of the density error. One hundred paired soundings (see tables 1 and 3) were used consisting of 51 Arcasonde to Arcasonde, 13 Datasonde to Datasonde, seven sphere to sphere, five Arcasonde to sphere, eight Arcasonde to Datasonde, and 16 Datasonde to sphere comparisons. Any two soundings obtained within 4 hr of each other were grouped together as a pair (some soundings were used in more than one pair). It was assumed that each of two sets of observed data is composed of a linear trend and zero mean Gaussian noise. In addition, the data were compared only over common data points and to an altitude of 65 km for the bead thermistor and to 85 km for the sphere data.

Following an analysis method described by Brownlee (1960), a straight line was fitted to the log of the density

TABLE 2.—*Mean density data of the various sounding series compared to the 1962 Standard Atmosphere*

Altitude	Bead thermistor data			1962 Standard Atmosphere	Sphere data		
	Apr. mean	May mean	Feb. mean		Feb. mean	May 9, 1100 MST	May 10, 2000 MST
(km)	($gm \cdot m^{-3}$)	($gm \cdot m^{-3}$)	($gm \cdot m^{-3}$)	($gm \cdot m^{-3}$)	($gm \cdot m^{-3}$)	($gm \cdot m^{-3}$)	($gm \cdot m^{-3}$)
30	18. 1351	18. 4798	17. 1079	18. 410	—	—	—
32	13. 1735	13. 4044	12. 3203	13. 555	—	—	—
34	9. 6714	9. 8562	9. 2116	9. 8874	—	—	—
36	7. 0984	7. 3636	7. 0613	7. 2579	—	—	—
38	5. 2515	5. 4225	5. 3301	5. 3666	—	—	—
40	3. 8649	4. 0379	3. 9930	3. 9957	—	—	—
42	2. 9332	3. 0127	3. 0112	2. 9948	—	—	—
44	2. 2669	2. 3287	2. 2646	2. 2589	—	—	—
46	1. 7752	1. 8046	1. 7349	1. 7141	—	1. 9374	1. 9451
48	1. 3606	1. 4172	1. 3496	1. 3167	1. 3739	1. 5281	1. 4977
50	1. 0795	1. 1157	1. 0616	1. 0269	1. 0833	1. 1454	1. 2189
52	0. 8419	0. 8664	0. 8331	0. 8010	0. 8497	0. 8610	0. 9242
54	. 6568	. 6757	. 6591	. 6314	. 6612	. 6628	. 7673
56	. 5162	. 5252	. 5080	. 4976	. 4917	. 5397	. 5467
58	—	. 4143	. 4013	. 3909	. 3973	. 4423	. 4182
60	—	—	. 3188	. 3059	. 3153	. 3303	. 3502
62	—	—	. 2489	. 2393	. 2462	. 2633	. 2601
64	—	—	. 1925	. 1884	. 1912	. 2047	. 2106
66	—	—	—	. 1471	. 1488	. 1537	. 1602
68	—	—	—	. 1140	. 1129	. 1148	. 1277
70	—	—	—	. 0875	. 0845	. 0883	. 0992
72	—	—	—	. 0666	. 0584	. 0643	. 0697
74	—	—	—	. 0501	. 0425	. 0481	. 0505
76	—	—	—	. 0374	. 0329	. 0349	. 0360
78	—	—	—	. 0275	. 0263	. 0248	. 0268
80	—	—	—	. 0199	. 0198	. 0172	. 0199

TABLE 3.—*Additional soundings used in the density noise determination*

Date	Time	Sensor
1967	(MST)	
Mar. 22	1941	Arcasonde
Mar. 22	1946	Datasonde
June 21	1250	Arcasonde
June 21	1300	Datasonde
1968		
July 10	2134	Datasonde
July 10	2159	Datasonde
July 10	2225	Datasonde
July 10	2249	Datasonde
1969		
May 28	1804	Datasonde
May 28	1929	Arcasonde
Nov. 20	1030	Sphere
Nov. 20	1031	Sphere
1970		
June 3	1745	Arcasonde
June 3	1755	Datasonde
June 9	1620	Datasonde
June 9	1630	Datasonde

values and a slope, $\hat{m}$, and an intercept, $\hat{b}$, were computed for each sounding in each pair. The variance of the residuals, $\hat{\sigma}^2$, about each line was calculated. For each pair, the F-test was used to determine if the two residual variance estimates were significantly different. If the hypothesis of equal population variances could not be rejected, then the two sample variances were combined to obtain a better estimate of the population variance of the noise. Using this improved estimate of the noise variance, the difference between the two computed slopes was tested to determine if the difference was significant. Failure to reject the hypothesis that the two slopes were the same led to the conclusion that the two real lines in each pair could be considered parallel. Under these conditions, the two sample slopes were then combined to get a better estimate of the true slope. A revised estimate of the noise variance was computed using the improved estimate of the slope and the previously calculated intercepts. The updated noise variance estimate was used to determine if the difference between the two calculated intercepts was significant. Failure to reject the hypothesis of equal intercepts led to the conclusion that the lines were not only parallel but also coincident. Under these conditions, the two soundings were combined to obtain new estimates of noise variance, slope, and intercept. Only those pairs that indicated coincident lines were retained for further analysis and in each pair the straight line accounted for 99.6–99.9 percent of the total variance of the values of log density. Under the assumption of white noise in the log density values, 55 of the total of 100 pairs indicated coincident lines. The breakdown is as follows: 38 of 51 Arcasonde–Arcasonde pairs, 10 of 13 Datasonde–

456-793 O - 72 - 3

TABLE 4.—*A listing of the various standard deviations of density errors*

Type of paired sensor	Standard deviation of density error ($\%\tilde{\sigma}$)
Arcasonde–Arcasonde	0.75
Datasonde–Datasonde	0.77
Arcasonde–Datasonde	1.38
*Arcasonde–Sphere	1.94
*Datasonde–Sphere	2.17
*Sphere–Sphere	2.86(0.93)†

*All data were used in these cases so that a comparison could be made.
†Value for the two soundings that indicated coincident lines.

$$\overline{\%\hat{\sigma}}=\sqrt{\frac{\sum_{i=1}^{m}(\%\hat{\sigma}_i)^2 n_i}{\sum_{i=1}^{m} n_i}}$$

$$\%\tilde{\sigma}=\frac{\overline{\%\hat{\sigma}}}{\sqrt{2}}$$

which yields the standard deviation of the error in density data.

Datasonde pairs, five of eight Arcasonde–Datasonde pairs, two of seven sphere–sphere pairs, zero of five Arcasonde–sphere pairs, and zero of 16 Datasonde–sphere pairs. Using the soundings that indicated coincident lines, a first estimate of the standard deviation of the random errors of density data was calculated (see table 4). The fact that only two of seven sphere pairs indicated coincident lines and none of the Arcasonde–sphere or Datasonde–sphere pairs showed coincident lines suggests that the sphere-derived densities are different from the bead thermistor-derived densities as well as having a large within-group variation.

Next, the differences between the log density values of all pairs were pooled and a histogram was constructed. The distribution function for the differences was not significantly different from a normal distribution with a mean of zero. For the analysis of variance, the data were divided into three time groups. Group 1 included all the density differences between pairs indicating coincident lines with time between the soundings making up the pair being less than 1 hr. Group 2 included time separation of 1–2 hr, and Group 3 included time separation of 2–4 hr. No sphere data were used in this part of the analysis because sphere data were judged to be significantly different from the bead thermistor data. For each group, a mean percentage difference in density was computed that can be considered the percentage change in density in the particular time span. Group 1 showed a percentage change of 0.21 with 95-percent confidence limits of ± 0.11 percent about this value. The percentage change for Group 2 was 0.32 with 95-percent confidence limits of ± 0.12 percent, and for Group 3 the percentage was 1.22 with 95-percent confidence limits of ± 0.16 percent.

To obtain a better estimate of the total density error and to determine if time variation accounted for a significant change in density, we made another F-test (table 5).

TABLE 5.—*Analysis of variance*

	Sum of squares (SS)	Degrees of freedom	Mean square (MS)	F ratio*
Between group (C)	259.8	2	129.69	
Within group (E)	3,912.00	1,676	2.33	55.66
Total	4,171.80	1,678	2.49	

*F-ratio = MSC/MSE = 129.69/2.33 = 55.66 for 2 and 1,676 degrees of freedom
F-ratio at 1% level = 4.62
$\overline{\%\hat{\sigma}}$ (random errors) = $\sqrt{2.33}/\sqrt{2}$ = 1.08%
95% confidence limits = 1.08 (±1.96) = ±2.12%

The sum of the squares of the differences of the percent difference in density values about their group means was determined using 1,679 data points. An estimate of the population variance of these differences (MSE), which is an estimate of twice the population variance of the total density error, was found to be 2.33 percent. Then an estimate of the population variance of the group means about their mean (MSC) was found to be 129.69. The F-ratio (F=MSC/MSE) was 55.66 for two and 1,676 degrees of freedom, which is significant at the 1-percent level and indicates a definite time variation effect. Now the best estimate of the standard deviation of the density noise is 1.08 percent. Density noise is defined as the ratio of the difference between the observed and true density to the true density.

6. SUMMARY AND CONCLUSIONS

Possible errors in the measurement of stratospheric temperature using bead thermistors and the resultant computation of atmospheric density are evaluated. Results indicate that significant errors in density could result from the values used from the tie-on radiosonde. Therefore, it seems important to replace the radiosonde values in the reduction procedure with values derived from a pressure sensor that is flown with the rocketsonde temperature sensor. Such systems have been used at WSMR (Thiele and Beyers 1967), in the Soviet Union (Alekseyev et al. 1962), and in Australia (Beach and Hind 1970).

The repeatability of the bead thermistor data presented in this paper was good while bead thermistor data and data from inflatable spheres showed poor agreement on an individual basis. However, the agreement between the mean of five bead thermistors and the mean of four inflatable spheres flown on the same day was good. In other words, the variance of the sphere data was larger than that of the bead data.

The best estimate of the density noise was found to be 1.08 percent for the Datasonde and Arcasonde instruments.

REFERENCES

Alekseyev, P. P., Besyadoyskiy, Ye. A., Biryukova, L. A., Golyshev, G. I., and Ivanovskiy, A. I., "Investigation of Upper Atmosphere Layers by Means of Meteorological Rockets," *Translation* TT–F–168, National Aeronautics and Space Administration, Greenbelt, Md., **1964**, pp. 131–152.

Ballard, Harold N., "A Review of Seven Papers Concerning the Measurement of Temperature in the Stratosphere and Mesosphere," *Technical Report* ECOM–5125, U.S. Army Electronics Command, Ft. Monmouth, N.J., May **1967**, 67 pp.

Ballard, Harold N., and Rubio, Roberto, "Corrections to Observed Rocketsonde and Balloonsonde Temperatures," *Journal of Applied Meteorology*, Vol. 7, No. 5, Oct. **1968**, pp. 919–928.

Beach, C. J., and Hind A. D., "A Rocketborne Meteorological Dropsonde," *Technical Memorandum* HSA 203, Weapons Research Establishment, Adelaide, South Australia, Jan. **1970**, 36 pp.

Beyers Norman J. and Miers. Bruce T., "Measurements From a Zero-Pressure Balloon in the Stratopause (48 km)," *Journal of Geophysical Research, Oceans and Atmospheres*, Vol. 75, No. 18, June 20, **1970**, pp. 3513–3522.

Brownlee, K. A., *Statistical Theory and Methodology in Science and Engineering*, John Wiley and Sons, Inc., New York. N.Y., **1960**, 570 pp.

Camp, Dennis W., and Caplan, Frank E., "High Resolution Balloonborne Temperature Sensor," *Journal of Applied Meteorology*, Vol. 8, No. 1, Feb. **1969**, pp. 159–166.

COESA, U.S. Committee on Extension to the Standard Atmosphere, *U.S. Standard Atmosphere, 1962*, Government Printing Office, Washington, D.C., **1962**, 278 pp.

Engler, Nicholas A., "Development of Methods to Determine Winds, Density, Pressure, and Temperature From the ROBIN Falling Balloon," *Final Report*, Contract No. AF19(604)–7560, AFCRL–65–448, University Research Institute, Dayton, Ohio, May **1965**, 141 pp.

Faucher, G. A., Morrissey, J. F., and Stark, C. N., "Falling Sphere Density Measurements." *Journal of Geophysical Research*, Vol. 72, No. 1, Jan. 1, **1967**, pp. 299–305.

Inter-Range Instrumentation Group, Meteorological Working Group, *Meteorological Equipment Data Accuracies*, Document 110–64, Secretariat, Range Commanders Council, White Sands Missile Range, N. Mex. **1965**, 34 pp.

Kays, Marvin D., and Avara, E. P., "Errors Associated With Meteorological Data Above 30 Km," *Technical Report*, ECOM–5295, U.S. Army Electronics Command, Ft. Monmouth, N.J., Apr. **1970**, 25 pp.

Luers, James, and Engler, Nicholas A., "High-Altitude Robin Data-Reduction Program," *NASA Special Publication* SP–219, U.S. National Aeronautics and Space Administration, Washington, D.C.. Sept. **1969**, pp. 111–143.

Miller, Alvin J., and Schmidlin, Francis J., "Rocketsonde Repeatability and Stratospheric Variability," *Journal of Applied Meteorology*, Vol. 10, No. 2, Apr. **1971**, pp. 320–327.

Morris, James E., and Miers, Bruce T., "A Climatology of the Upper Atmosphere," *Progress in Astronautics and Aeronautics*, Vol. 22, No. 2, Academic Press, Inc., New York, N.Y., Oct. **1969**, pp. 531–553.

Muench, H. Stuart, "Temperature Measurements in the 30- to 40-Kilometer Region," *Monthly Weather Review*, Vol. 99, No. 2, Feb. **1971**, pp. 158–160.

Novotny, R. D., and Grazier, G., "Rocketsonde Data Reduction," *Report* 634B, Environmental Technical Applications Center, U.S. Air Force, Washington, D.C., Oct. **1970**, 77. pp.

Pearson, P. H. O. "Seasonal Variations of Density, Temperature and Pressure Between 40 and 90 km, Woomera, South Australia, March 1964–March 1965," *Journal of Atmospheric and Terrestrial Physics*, Vol. 28, No. 11, Headington Hill Hall, Oxford, England, Nov. **1966**, pp. 1057–1064.

Thiele, Otto W., and Beyers, Norman J., "Comparison of Rocketsonde and Radiosonde Temperatures and an Evaluation of Computed Rocketsonde Pressure and Density." *Journal of Geophysical Research*, Vol. 72, No. 10, May 15, **1967**, pp. 2485–2495.

Vennard, J. K., *Elementary Fluid Mechanics*, John Wiley and Sons, Inc., New York, N.Y., **1940**, 243 pp.

National Oceanic and Atmospheric Administration, World Data Center A—Meteorology, *High Altitude Meteorological Data*, Vols. VI, Nos. 4 and 5, **1969**, and VII, No. 2, **1970**, Asheville, N.C.

Wright, John B., "A Summary of AFCRL Passive-Sphere Development Efforts and Experience," *NASA Special Publication*, SP–219, U.S. National Aeronautics and Space Administration, Washington, D.C., Sept. **1969**, pp. 1–38.

[*Received December 23, 1970; revised September 30, 1971*]